4. LANDSCAPE IMPACT ASSESSMENT FOR WATERCOURSES AND SWAMPS

In developing the mine plan for Area 3A, IC have committed to avoiding major impacts on the significant watercourses of Wongawilli and Sandy Creeks. They will not be directly undermined and are located at minimum distances of 115 metres and 100 metres, respectively, from the proposed Area 3A longwalls. MSEC have predicted that it is unlikely, that there would be any significant fracturing or flow diversions along these creeks, as a result of the extraction of the proposed longwalls.

This commitment to avoiding major impacts on the significant watercourses of Wongawilli and Sandy Creeks has also been made for Areas 3B and 3C. Hence, this section focuses on other natural features of the landscape which are the swamps and minor watercourses.

4.1. WATERCOURSES AND SWAMP LOCATIONS

Figure 4.1 shows the locations of watercourses and swamps within mining area 3A, and the location of the proposed longwalls.

Figure 4.2 shows the locations of watercourses and swamps within the entire proposed Area 3 footprint. It is noted that the mining plans for Areas 3B and 3C have not yet been determined, and therefore no longwall layouts are presented in **Figure 4.2**.

4.2. RISK FACTORS FOR WATERCOURSES AND SWAMPS

Table 4.1 outlines the risk factors considered and assessed for watercourses and swamps. The primary factors are subsidence related. A large database of subsidence prediction, and monitoring data has been collected on behalf of IC by MSEC since the early 1990's. The *subsidence related* risk factors in **Table 4.1** have been identified in consultation with MSEC, by correlation of subsidence prediction/ monitoring data from IC mines and observed landscape impacts.

Other landscape or hydrology related risk factors are also listed in **Table 4.1** and the justification for their analysis is outlined. These risk factors have been identified by various previous studies by MSEC, EarthTech (2003, 2005) and Palamara et al (2006). These risk factors include:

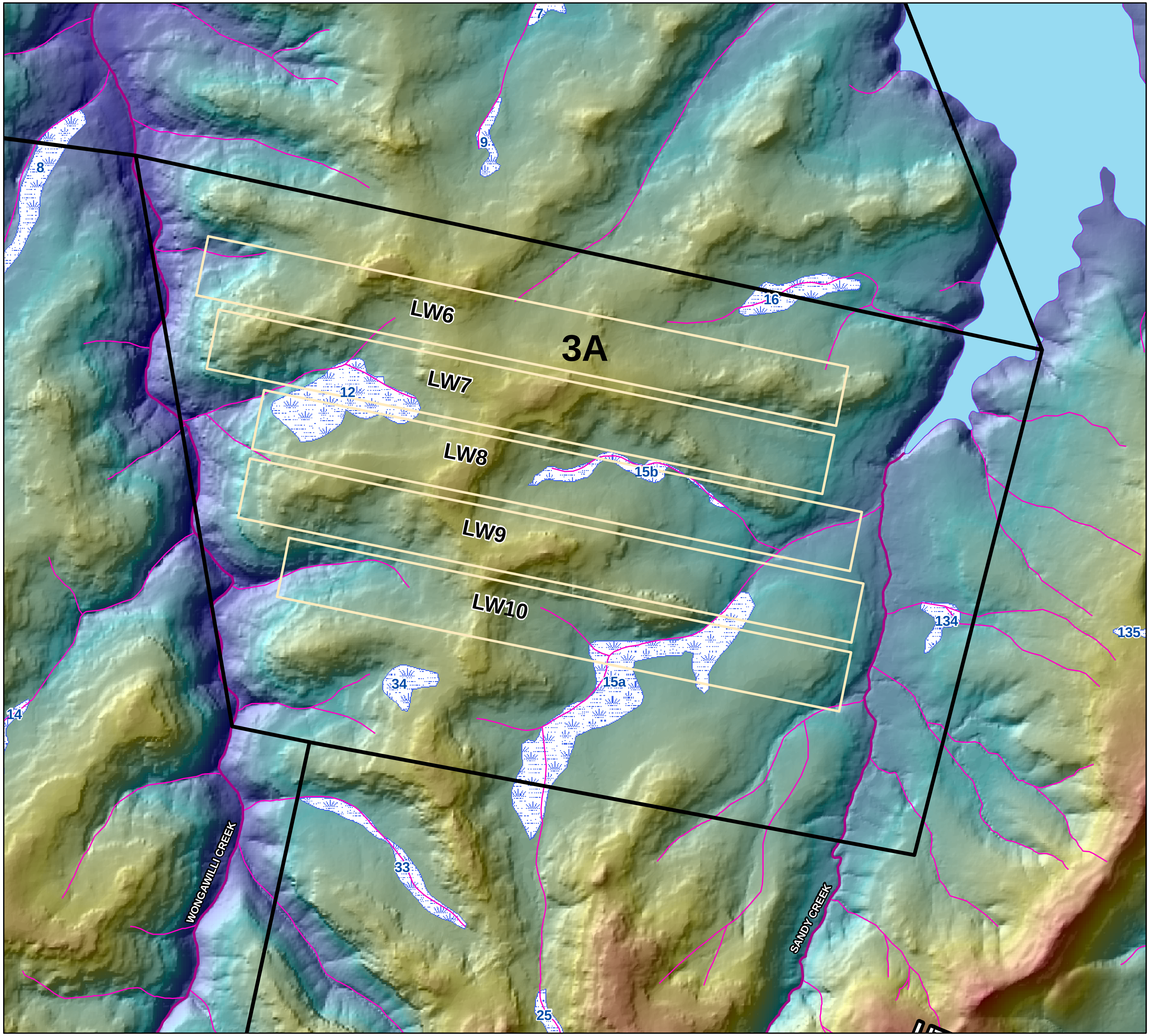
- High stream order (catchment area)
- Catchment Area Change
- Slope Gradient Change
- Vegetation Cover
- Soil Landscape Type
- Slope Length
- Swamps oriented perpendicular to longwalls
- Location of swamp within Catchment

- Fire History & Climatic Events
- Existing Points of disturbance

Earthtech (2005) have previously identified swamp systems at greatest risk to increased scour as having the following characteristics:

- High stream order (catchment area)
- Poor vegetation condition;
- Swamps oriented perpendicular to longwalls
- Swamps located across the subsidence trough perimeter (subject to greater potential changes in gradient)

Earthtech (2005) reviewed velocity and shear stress thresholds of different vegetation types from the literature and subsequently determined indicative velocity and shear stress thresholds for swamps of the Woronora plateau. They proposed that these thresholds could be used for comparative purposes in future assessments to determine whether instabilities in swamps were likely. This can be done by modelling of subject swamps/watercourses and comparing the estimated velocity and shear stresses with the thresholds. Such comparisons are undertaken below.



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Swamps and Watercourses

DENDROBIUM AREA 3A

- Proposed Area 3 Footprint
- Mine Layout - SMP Area 3A
- Swamps
- Lakes
- Rivers
- Creeks
- Minor Streams

Elevation:

- 500 - 550m
- 450 - 500m
- 425 - 450m
- 400 - 425m
- 350 - 400m
- 275 - 300m

N
W E
S

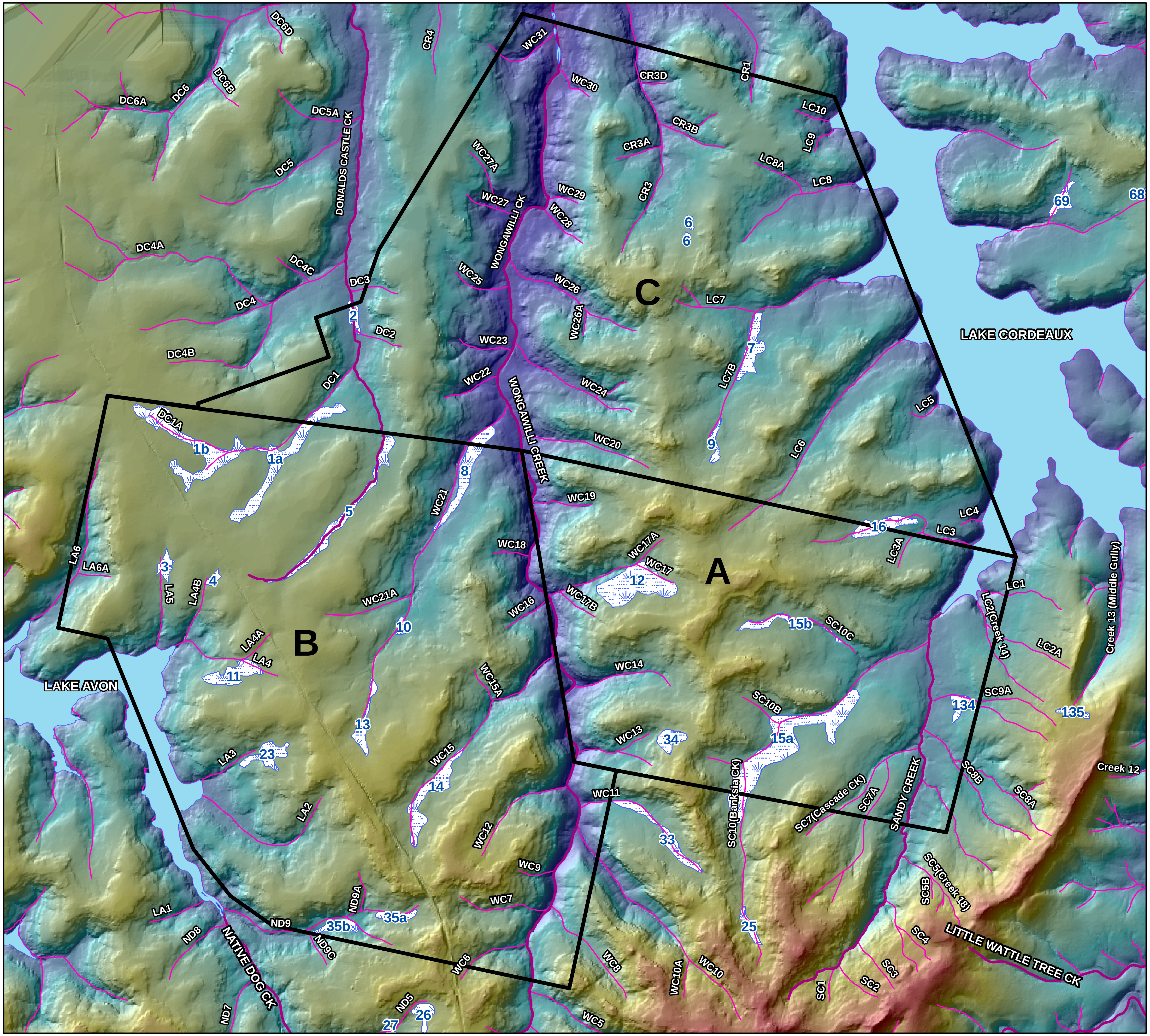
FIGURE 4.1

Scale 1:15,000 (at A3)

Metres
0 250 500

Cardno Forbes Rigby

Map Produced by Forbes Rigby Pty Ltd
Date:6 September 2007
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF:
107055_02_2815_Swamps_Area3A.mxd



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Swamps and Watercourses

DENDROBIUM AREA 3

Proposed Area 3 Footprint
Swamps
Lakes
Rivers
Creeks
Minor Streams

Elevation:
500 - 550m
450 - 500m
425 - 450m
400 - 425m
350 - 400m
275 - 300m

N
W
E
S

FIGURE 4.2

Scale 1:27,500 (at A3)

Metres
0 250 500 1,000

Cardno Forbes Rigby

Map Produced by Forbes Rigby Pty Ltd
Date:4 September 2007
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF:
107055_02_2814_Swamps_Area3.mxd

Table 4.1 - Landscape Impact Risk Factors for Watercourses and Swamps

Primary Risk Factors (Subsidence Related)	Justification
Cumulative Subsidence (mm)	May result cause differential movements and strains. Modified surface contours may lead to changes in catchment distribution for creeks and swamps.
Cumulative Tilt (mm/m)	Increased gradient in watercourses/swamps could lead to increased flow velocities and potentially increased erosion of susceptible “nick” points Decrease in gradient may lead to pooling of water that may lead to increased flooding of the immediate area or erosion of susceptible “nick” points
Cumulative Tensile Strains (mm/m)	May result in fracturing of sandstone, especially where predicted maximums exceed 0.5 mm/m. This may lead to diversion of surface flow into fractured strata, surface water flow losses and impacts on aquatic ecology
Cumulative Compressive Strains (mm/m)	May result in fracturing (buckling) of sandstone especially where predicted maximums exceed 2 mm/m. This may lead to diversion of surface flow into fractured strata, surface water flow losses and impacts on aquatic ecology
Cumulative Closure (mm)	Major fracturing/flow diversion impacts have been observed when valley closure over 200mm was predicted.

Secondary Risk Factors (Landscape Related)	Justification
High stream order (catchment area)	Larger catchment areas generate higher flows, which may cause erosion when combined with other factors such as grade changes, poor vegetation cover or existing erosion or nick points.
Post Mining Catchment Area Change	Increases in catchment size may generate higher flows, which may cause erosion when combined with other factors such as grade changes, poor vegetation cover or existing erosion or nick points. Decreases in catchment size will reduce flows and therefore the water available to swamp ecosystems. Altering the hydrological balance may potentially lead to changes in species composition of swamp vegetation and fauna.
Slope Gradient Change	Depending on the existing gradient of the swamp/creek: Increased gradient in watercourses/swamps could lead to increased flow velocities and potentially increased erosion of susceptible “nick” points Decrease in gradient may lead to pooling of water that may lead to increased flooding of the immediate area or erosion of susceptible “nick” points Significant gradient changes could potentially increase flow velocity (although this would only occur on sites with a very low existing grade)
Vegetation Cover	Increased chances of soil erosion in poorly vegetated or disturbed soils
Moisture Conditions and groundwater environment	Evidence of permanent groundwater flow/supply by shallow hillslope aquifers would indicate a swamp is less susceptible to potential subsidence induced hydrological changes
Soil Landscape Type	Varying classes of soil erodibility depending on soil landscape

Bed Controls	Swamps with sandstone bases as the bed control within primary drainage lines would be less likely to experience increased bed erosion due to potential mining induced flow increases or gradient changes
Slope Length	Increased risk of scouring with increased length
Swamps oriented perpendicular to longwalls	Swamps located wholly within or parallel to longwalls are exposed to less differential subsidence than swamps laying perpendicular to, or across longwalls. Swamps laying across longwalls are subject to more gradient changes reflecting the subsidence troughs of each longwall. That means there are will be points of potential increase in scour or pooling for each subsidence trough the swamps traverses. The more subsidence troughs (longwalls) the swamp traverses, the more risk of that swamp experiencing scour or pooling at points of maximum grade changes (if that grade change is significant compared to existing grades).
Location of swamp within Catchment	Previous investigations by Earthtech 2003, indicate that no local valley side and headwater) swamps show evidence of significant scouring, while valley floor swamps have shown contemporary and historical evidence of scour. It is believed this may be due to the confined nature of valley floor swamps, constrictions with increased gradients, increased catchment areas, and therefore erosional capability in high flows.
Fire History & Climatic Events	Recent Fire can lead to increased chances of soil erosion due to vegetation and peat damage Drought can reduce vegetation cover and damage vegetation, leaving the swamps predisposed to a higher risk lead to increased chances of soil erosion in rain events.
Existing Points of disturbance	Existing disturbed channels/soils represent increased chances of soil erosion in rain events.

4.3. LANDSCAPE IMPACT ASSESSMENT FOR WATERCOURSES AND SWAMPS IN AREA 3

4.3.1. Location of Swamps within the Catchment

The relative location and characteristics for each swamp in Area 3 is outlined in **Table 4.3.** They have been generally been classified after EarthTech (2003) as described below:

Valley Floor Swamps

Valley floor swamps are swamps on valley floors that occupy the main drainage line. Valley floor swamps tend to be linear, though they may be branched. Generally the swamps contain no permanent channel, but rather a series of preferred flow paths and sections of discontinuous channel and ponds. The branched form of these swamps tend to have their branches occurring on elevated steps above the main swamp though still in valley floor positions within their respective valleys.

It has been noted during the field investigations by EarthTech that these swamps contained many more initiation points for scouring such as ponds and sections of discontinuous channel than the other categories of swamp. Valley floor swamps were found to be the only swamps to have shown any history of scour and recovery through the historical aerial photo interpretation.

Valley Side:

Valley side swamps were identified as occurring where seepage emerges along the bedding planes (Young, RW and ARM, 1988) within the Cataract catchment, and are fed by short, gentle benched slopes (Young, 1982). Valley Side swamps may also consist of a series of steps.

Headwater Swamps:

Headwater swamps, have a mixture of Valley Side and Valley Floor swamp characteristics. Headwater swamps are found in the very upper reaches of the catchment. These swamps often form a shelf/amphitheatre around the drainage gully with erosion resistant sandstone shelf restraining the swamps. The swamps in the amphitheatre may form at a series of different levels depending on the local geology. The swamps are largely dependant on shallow groundwater.

EarthTech (2003) have noted low order streams typically have the steepest stream gradient and the smallest catchment area. As the order increases, the catchment area increases and the stream gradient generally decreases. As catchment area increases, the volumes of water increase and channelisation becomes inevitable. Swamps situated on streams of high stream order are quite rare and have the lowest grades. These swamps therefore have the highest consequence of the impact of subsidence.

Table 4.3 outlines the respective stream order and catchment area for *each swamp* (not the actual total sub catchment area) in Area 3.

By referring to **Figure 4.2**, the stream order and catchment areas noted in **Table 4.3,** Swamps 2, 5, 7, 8 and 15a appear to be the swamps at most potential risk of undergoing scour due to their downstream location on the drainage channel, large catchment area, and therefore magnitude of flows that may be expected in large rain events.

An example of the flows that may be expected at the downstream end of these swamps has been estimated using the WBNM model, and is provided below. Hydrographs and flow data are attached in **Appendix B**.

Table 4.2 - Flows for 2 and 50 yr Events for Swamps 2, 5, 7, 8 and 15a

Swamp	2yr ARI, 2hr duration storm Peak Flow (m^3/s)	50yr ARI, 2hr duration storm Peak Flow (m^3/s)	100yr ARI, 2hr duration storm Peak Flow (m^3/s)
1a	1.5	11.2	14.1
2	4.7	27.3	34.5
5	1.2	8.6	10.8
7	3.0	14.3	17.9
8	6.4	29.0	35.9
15a	3.3	18.0	22.5

4.3.2. Catchment Area Change

The potential to alter catchment boundaries (and therefore catchment areas) was noted by IC as a result of preliminary investigations undertaken by the UOW (Palamara 2006a) in the application of GIS to investigate/monitor mine subsidence. IC specifically requested this issue be investigated as part of this report.

Increases in catchment size may generate higher flows, which potentially may cause increased erosion when combined with other factors such as grade changes, poor vegetation cover or existing erosion or nick points.

Decreases in catchment size may reduce flows and therefore the water available to swamp ecosystems. Altering the hydrological balance may potentially lead to changes in species composition of swamp vegetation and fauna.

Analysis Undertaken

IC supplied an ALS Survey of the area in and around the proposed longwalls for Dendrobium Area 3A. The survey was converted into a digital terrain model (DTM) and one metre contours were created to delineate the pre-mining creek and swamp catchments. A large-scale map containing the location of the proposed long walls, creeks, swamps and one metre contours was plotted. Creek and swamp catchments were then manually interpreted and drawn onto the plan. An automatic catchment delineation tool within AutoCAD was found to be unsatisfactory for this detailed catchment mapping.

The plan was then scanned into AutoCAD and the catchment boundaries traced. After the catchments were traced into AutoCAD the plan was re-plotted, this time containing the catchments. From this new plan, a check of the catchment location was undertaken to ensure all the catchments were correctly mapped. Minor manual adjustments were made to ensure that the catchments run along the middle of ridges and connected into the base of creeks. Refer to the pre-mining catchment plan in **Appendix A.**

Table 4.3 - Dendrobium Area 3 Swamp Risk Analysis

Swamp Name à	Swamp 1a	Swamp 1b	Swamp 2	Swamp 3	Swamp 4	Swamp 5	Swamp 6	Swamp 7	Swamp 8	Swamp 9	Swamp 10	Swamp 11
Primary Risk Factors (Subsidence Related)												
Is swamp likely to overlie future Goaf Area	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Likely Cumulative Subsidence (mm)	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300	Est. 1700-2300
Likely Cumulative Tilt (mm/m)	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25	Est. 15-25
Likely Cumulative Tensile Strains (mm/m)	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6	Est. 3-6
Likely Cumulative Compressive Strain (mm/m)	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15	Est. 5-15
Likely Maximum Cumulative Closure (mm)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Risk of Surface Cracking	Likely	Likely	Likely	Likely	Likely	Likely	Likely	Likely	Likely	Likely	Likely	Likely
Risk of Flow Diversion into Strata	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Possible
Secondary Risk Factors (Landscape Related)												
Location of Swamp within Catchment	Valley side	Headwater swamp	Valley floor	Headwater swamp	Headwater swamp	Valley floor	Headwater	Valley floor	Valley floor	Headwater swamp	Valley Side	Headwater swamp, valley side
Stream Order and Catchment Area of Swamp	2nd Order 1,213,359m2	1st Order 750,903m2	2nd Order 2,498,456m2	1st Order 260,010m2	1st Order 103,193m2	1st Order 794,707m2	Not on a stream 24,438m2 (north section) 63,416m2 (south section)	1st Order 1,118,900m2	2nd Order 2,407,110m2	1st Order 299,307m2	1st Order 883046m2	1st Order 306261m2
Slope Length (m)	1125m	960m	280m	260m	160m	1500m	118m (north section) 92m (south section)	551m	930m	372m	147m	495m
Post Mining Catchment Area Change	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Existing Mean Gradient	3.9%	2.4%	1.6%	4.6%	6.3%	2.9%	5.9% (north section) 7.6% (south section)	2.9%	5.1%	4.6%	4.8%	5.3%
Existing Maximum Gradient	10.7%	6.2%	6.1%	8.0%	10.0%	25.0%	5.9% (north section) 7.6% (south section)	7.7%	36.0%	7.6%	11.1%	13.0%
Maximum Post Mining Slope Gradient Change	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Swamps Oriented Across (Perpendicular to) or along (parallel to) Longwalls	Across	Across	Across	Across	Across	Across	Across	Across	Across	Across	Across	Across
Vegetation Cover	ND	ND	ND	ND	ND	Well Vegetated	ND	Well Vegetated	ND	Moderately Vegetated	Well Vegetated. Possible vegetation stress due to prolonged drought period.	Well Vegetated. Possible vegetation stress due to prolonged drought period.
Moisture Conditions and Groundwater Environment	ND	ND	ND	ND	ND	Usually dry, swamp does not retain surface water for more than a few days after rainfall	ND	Always moist, surface water visible, even in drought	ND	Moderately moist, no surface water during drought	Always moist, moist to wet soil even in drought	Always moist, surface water visible, even in drought
Bed Controls	ND	ND	ND	ND	ND	No main drainage path observed	ND	Exposed basal rock bar	ND	No main drainage path observed	No photos	No main drainage path observed, water flow over basal step
Soil Landscape Type & Concentrated Flow Erodibility	Penrose Variant A (DS portion) - Moderate-High / Stockyard Swamp (middle portion) - Moderate-High / Lucas Heights (US portion) - Moderate	Stockyard Swamp (DS portion) - Moderate-High / Lucas Heights (US portion) - Moderate	Gymea – High-extreme	Stockyard Swamp (DS portion) - Moderate-High / Lucas Heights (US portion) - Moderate	Lucas Heights - Moderate	Penrose Variant A (DS portion) - Moderate-High / Lucas Heights (US portion) - Moderate	Gymea – High-extreme	Penrose Variant A - Moderate-High	Penrose Variant A (DS portion) / Stockyard Swamp (US portion) - both Moderate-High	Penrose Variant A - Moderate-High	Stockyard Swamp (DS portion) / Penrose Variant A (US portion) - both Moderate-High	Stockyard Swamp (DS portion) / Penrose Variant A (US portion) - both Moderate-High
Fire History & Climatic Events	Extreme burning 2001/2002	Extreme burning 2001/2002	Medium-high burning 2001/2002	Extreme burning 2001/2002	Medium burning 2001/2002	Extreme burning 2001/2002	Medium-high burning 2001/2002	Extreme burning 2001/2002	Medium-extreme burning 2001/2002	Medium-high burning 2001/2002	Extreme burning 2001/2002	Extreme burning 2001/2002
Existing Points of Disturbance	ND	ND	ND	ND	ND	Some scoured pools at the downstream end of	ND	No existing disturbed channels or soils identified	ND	Significant scoured channel	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified

						pond						
Overall Risk Rating from Landscape Related Factors	Low	Low	Low	Low`	Low	Moderate	Low	Low	Moderate	Low	Low	Low

Swamp Name à	**Swamp 12**	**Swamp 13**	**Swamp 14**	**Swamp 15a**	**Swamp 15b**	**Swamp 16**	**Swamp 23**	**Swamp 34**	**Swamp 35a**	**Swamp 35b**	**Swamp 134**
Primary Risk Factors (Subsidence Related)											
Is swamp likely to overlie future Goaf Area	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	No
Likely Cumulative Subsidence (mm)	1900	Est. 1700-2300	Est. 1700-2300	2275	2115	70	Est. 1700-2300	40	Est. 1700-2300	<100	<100
Likely Cumulative Tilt (mm/m)	17	Est. 15-25	Est. 15-25	21	15	1.1	Est. 15-25	0.5	Est. 15-25	<2	<2
Likely Cumulative Tensile Strains (mm/m)	4	Est. 3-6	Est. 3-6	3.8	4.5	0.3	Est. 3-6	0.1	Est. 3-6	<0.5	<0.5
Likely Cumulative Compressive Strain (mm/m)	7.1	Est. 5-15	Est. 5-15	11	7.1	0.1	Est. 5-15	<0.1	Est. 5-15	<2	<2
Likely Maximum Cumulative Upsidence (mm)	665	ND	ND	290	345	ND	ND	ND	ND	ND	ND
Likely Maximum Cumulative Closure (mm)	650	ND	ND	200	265	ND	ND	ND	ND	ND	ND
Risk of Surface Cracking	Likely	Likely	Likely	Likely	Likely	Unlikely	Likely	Unlikely	Likely	Unlikely	Unlikely
Risk of Flow Diversion into Strata	Possible	Possible	Possible	Possible	Possible	Unlikely	Possible	Unlikely	Possible	Unlikely	Unlikely
Secondary Risk Factors (Landscape Related)											
Location of Swamp within Catchment	Valley Side	Headwater swamp	Valley floor	Valley floor	Valley floor	Valley floor	Valley Side	Headwater swamp	Valley Side	Valley side	Valley Side
Stream Order and Catchment Area of Swamp	1st Order 530,0894m2	1st Order 326,875m2	1st Order 681766m2	3rd Order 1,794,002m2	1st Order 553,229m2	1st Order 484,437m2	1st Order 253,740m2	1st Order 73,722m2	1st Order 170,856m2	1st Order 679,012m2	2nd Order 277,047m2
Slope Length (m)	730m	611m	909m	1508m	868m	513m	425m	233m	332m	378m	175m
Post Mining Catchment Area Change	None detected	ND	ND	None detected	None detected	ND	ND	ND	ND	ND	ND
Existing Mean Gradient	7.3%	4.7%	3.4%	2.5%	4.0%	4.1%	8.7%	16.3%	5.7%	2.9%	5.7%
Existing Maximum Gradient	34.0%	11.1%	9.1%	66.7%	8.6%	7.9%	31.3%	31.6%	16.7%	7.7%	10.3%
Maximum Post Mining Slope Gradient Change	Gradient Increase 2.89%	ND	ND	Gradient Increase 0.52%-1.68% Gradient Decrease 1.26%	Gradient Increase 0.90%Gradient Decrease 0.38%	ND	ND	ND	ND	ND	ND
Swamps Oriented Across (Perpendicular to) or along (parallel to) Longwalls	Along & Across	Across	Across	Across	Along	Across	Across	Not mined under	Across	Across	Not mined under
Vegetation Cover	Well Vegetated	Well Vegetated	Well Vegetated	Well Vegetated	Well Vegetated	Well Vegetated	Well Vegetated	Well Vegetated	Well Vegetated	Well Vegetated	Moderately Vegetated
Moisture Conditions and Groundwater Environment	ND	Always moist, surface water visible, even in drought	Always moist, surface water visible, even in drought	Always moist, surface water visible, even in drought	Always moist, surface water visible, even in drought	Always moist, surface water visible, even in drought	Average moisture content classed as dry, surface water found only on top of basal step	Swamp starts to dry within 7 days of rain	Generally damp to wet – surface water observed at both inspections	Generally damp to wet - ephemeral flow only	Damp to wet. Inconsistent across swamp with pools in some areas and dry patches on others
Bed Controls	ND	Basal pool	Exposed basal / Sandstone Channel	Exposed Sandstone Channel	Exposed Sandstone Channel	No main drainage path observed	No main drainage path observed	Exposed Sandstone Channel	Exposed Sandstone Channel (northern edge of swamp)	Exposed Sandstone Channel (northern edge of swamp)	No main drainage path observed
Soil Landscape Type & Concentrated Flow Erodibility	Stockyard Swamp-high	Penrose Variant A - Moderate - High	Stockyard Swamp - Moderate-High	Stockyard Swamp-high	Stockyard Swamp-high	Stockyard Swamp - Moderate-High	Penrose Variant A (DS portion) - Moderate-High / Lucas Heights (US portion) - Moderate	Gymea - High-Extreme	Penrose Variant A - Moderate - High	Penrose Variant A - Moderate - High	Penrose Variant A - Moderate - High
Fire History & Climatic Events	Extreme burning 2001/2002	Extreme burning 2001/2002	Extreme burning 2001/2002	Extreme burning 2001/2002	Extreme burning 2001/2002	High-extreme burning 2001/2002	Extreme burning 2001/2002	High-extreme burning 2001/2002	Extreme burning 2001/2002	Extreme burning 2001/2002	High-extreme burning 2001/2002
Existing Points of Disturbance	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified	Some fire scars on southern margin of swamp	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified	No existing disturbed channels or soils identified
Overall Risk Rating from Landscape Related Factors	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

Mine Subsidence Engineering Consultants Pty Ltd (MSEC) supplied post mining subsidence contours. These contours were overlaid into the existing survey and a new DTM created to reflect the expected post mining condition ground surface. From the post-mining DTM, a new set of contours was created. A second plan was plotted with the longwalls, creek, swamps and post mining contours. The post-mining creek and swamp catchments were then manually drawn onto the plan. The plan was then scanned into AutoCAD and the catchment boundaries traced. After the catchments were traced into AutoCAD the plan was replotted, this time containing the post-mining catchments. From this new plan a check of the catchment boundaries was undertaken to ensure all the catchments were correctly mapped. Minor adjustments were made to ensure that the catchments run along the middle of ridges and connected into the base of creeks. Refer to the post-mining catchment plan in **Appendix A.**

Once the pre-mining and post-mining catchments were mapped they were both plotted onto the same map to check if there were any detectable catchment changes as a result of the predicted subsidence. The plan containing both pre and post-mining catchments showed no detectable difference in the catchments sizes as a result of the mine subsidence. Refer to the post-mining catchment plan in **Appendix A.**

Assessment

The steep nature of the mining areas can explain why no difference in catchment sizes could be seen as a result of the subsidence. Slopes of the drainage paths within swamps 12,15a & 15b varied from approximately 2.5 to 41%, with average slopes of 7%, 2.5% and 4% for those swamps respectively. The relatively steep slopes and dissected nature of the longwall area means that despite subsidence of up to approximately 2.0m, no significant horizontal movement of ridge locations, (and therefore change in catchment areas) is detectable. The sensitivity of the analysis is limited to 1m contours. This is evident on the pre- and predicted post -mining contour overlay plan in **Appendix A,** which clearly shows some change in post mining contours, but no change in the ridgeline, or catchment boundary location.

It would be expected that in more even, flat topography this type of analysis would be able to detect catchment size changes due to subsidence. In fact Palamara et al (2006a) have reported predicting potential catchment changes of up to 14% for a swamp in Area 2 of Dendrobium mine. It is noted however that the subject swamp could be considered a special case that was particularly susceptible to subsidence induced catchment change. This is because the swamp actually straddled a plateau ridgeline (catchment boundary) and therefore was actually located in two different catchments. Such a location is inherently predisposed to subsidence induced catchment change if the existing grades are very low.

Swamps at risk of hydrological changes due to mine subsidence induced changes to the catchment area or watershed are:

- those whose *catchment* are bounded by ridges with a very low relief that are susceptible to the subtle grade changes induced by the subsidence bowl;
- those located on or close to very low relief ridge lines (catchment boundaries) where significant differential subsidence will occur. (i.e. plateaus that lie across the subsidence perimeter and zones of maximum subsidence).

Since most swamps in Area 3 are located within a discrete valley at an elevation *below the ridgelines* which exceeds the maximum subsidence (taken to be 2.2m), and since the relief of most sub-catchment boundary ridgelines across Area 3 have an inherent surrounding relief (gradient) that exceeds the maximum estimated gradient changes from future predicted post mining subsidence troughs (ie. Approx 2.1%), we assess that it is unlikely the majority of swamps in Area 3 will be impacted by mining induced catchment change.

While detailed analysis has shown this to be the case for Area 3A, such impact on catchment change is dependent on the orientation of the mine layout and its comparison to ridgelines. The subcatchments in Area 3B will need detailed investigation once the mine layout is defined to confirm there are no catchment changes for swamps such as 1b, 1a, 4, 5 and 13, which appear to be the most susceptible to any such change due to their location on areas of low relief. Refer mean gradients in **Table 4.3**.

If any catchment area changes are identified in the future they are likely to be minor in nature, and not expected to represent a major impact to the swamps, given many of the headwater swamps are known to be fed by shallow hillslope aquifers (Ecoengineers 2007), and local minor changes in tilt are not expected to affect the drainage direction of these aquifers.

It would be expected that in more even, flat topography this type of analysis would be able to detect catchment size changes due to subsidence. It is noted the sensitivity of the analysis is limited to 1m contours, however even with higher resolution contours (say 0.5m) we believe it would be difficult to detect any significant catchment changes within Area 3, noting that the ALS survey data is accurate to approximately 0.3m.

Given that the predicted subsidence for future undermined areas within Areas 3B & 3C will be similar to the subsidence parameters predicted in Area 3A, we believe it is unlikely future mining within Area 3 will result in any significant subsidence induce catchment area changes that would result in significant changes to runoff patterns within the sub catchments.

Further detailed catchment analyses will be conducted in Areas 3B & 3C when mine layouts are confirmed (pending geological investigations) and submitted with the relevant subsidence management plan submissions.

4.3.3. Slope Length

Slope lengths within swamps are outlined in **Table 4.3.**

The slope length for the swamps within Area 3 varies from a minimum of 92m (southern section of Swamp 6) up to a maximum 1508m (Swamp 15a). The average slope length is approximately 570m. 75% of the swamps within Area 3 have slope lengths within the range of 150-990m.

4.3.4. Gradient Changes in Swamps and Watercourses

Average and maximum gradients in swamps and their watercourses within Area 3 are outlined in **Table 4.3.**

The *average* swamp gradient varies from a minimum of 1.6% (Swamp 2) up to a maximum 16.3% (Swamp 34). The overall average swamp gradient for all swamps within Area 3 is 5.1%. Approximately 90% of the swamps have average swamp gradients within the range of 2.2-8.1%.

The maximum swamp gradient varies significantly from 5.9% (northern section of Swamp 6) up to 66.7% (Swamp 15a). The average maximum swamp gradient is 16.2%. Approximately 80% of the swamps within Area 3 have maximum gradients of less than 30%.

Prior Impact Assessments of Mining Induced Gradient Change

Prior investigations to determine a range of stability thresholds for swamp systems on the Woronora Plateau have been undertaken on behalf of IC by EarthTech (2005).

The investigation included:

- A Review of literature for stability thresholds.
- Hydrologic and hydraulic analysis of a selection of swamps to assess their stability against identified thresholds.

Swamps 5, 8 and 10 were modelled using Hec Ras to determine the impact of predicted subsidence on shear thresholds. This was undertaken by modelling the predicted subsidence in the swamp over the length of a longwall (250m) to an extent (depth of 2.5m).

Analyses of modelling results indicate that increasing the gradient of these swamps has minimal effect on the shear stress values. The minimal impact on shear stress is a function of the existing steep nature of the swamps studied. The subject swamps have a change in elevation of between 7 and 13m over 250m length, while the amount of subsidence experienced (at Elouera Colliery) is estimated to be typically between 0.3 and 1.3m over 250m with the greatest recorded subsidence in the region being approximately 2.5m (G. Brassington, pers. com.).

Modelling results also showed that swamp stability values increase by the greatest magnitude where shear stress of existing swamp conditions are previously low. As this generally occurs where there is a gentle grade, it can be hypothesized that subsidence will have greatest impact on swamps situated on a gentle grade where greatest relative impact of subsidence occurs.

While EarthTech modelling results indicate that increasing the gradient of these swamps has *minimal effect on the shear stress values*, velocity modelling showed a direct correlation between velocity and longitudinal grade within swamps. Therefore this type of modelling was suggested by EarthTech as having the potential to assist in the analysis of a swamp both prior to and after mining has occurred.

Analysis of Potential Gradient Changes in Area 3

Using the DTM described above, pre and predicted post-mining sections were prepared along the main drainage lines in Area 3A which were occupied by swamps. These sections are denoted Creek 01, Creek 02 & Creek 03. Refer to the section layout plan in **Appendix A.**

Each section was analysed to detect areas of visible predicted post mining gradient change. Areas identified as demonstrating predicted post mining gradient change were evaluated further to determine the magnitude of the predicted post mining gradient change. Selected areas were measured off the sections and the existing versus predicted post mining gradients were established. The predicted post mining gradient change for that area was then calculated so that maximum gradients and average gradients for each swamp was determined. Refer to the Creek 01, Creek 02 & Creek 03 sections in **Appendix A.**

The analysis determined gradients within the Area 3A swamps and their watercourses vary from 2.5 to 41%.

Maximum gradients and average gradients for each swamp in Area 3A were also determined. Refer sections in **Appendix A.**

Points of potential pooling due to a subsidence induced grade decrease have been noted on the relevant sections. Refer sections in **Appendix A.**

The analysis determined that mining induced gradient increases due to subsidence ranged from 0% up to approximately 1.9% (in swamp 12). These results concur with the MSEC prediction curves which predict maximum gradient change at 2.1%

For swamp 12, the maximum 1.9% increase in grade where the existing grade is 7.4%, means that represents a 26% increase in grade within that small (40m) section of swamp. Refer Creek 01 section in **Appendix A.**

For swamp 15a, the greatest relative grade increase occurs at an upstream section where the existing grade of approximately 0.2% is predicted to increase to approximately 1.1%. This increase in grade represents a fivefold increase in grade within that small (60m) section of swamp. Refer Creek 02 section in **Appendix A.**

Several points of gradient decrease are also noted for swamp 15a with the greatest being over longwall 9, with a predicted change of approximately 1.2%. It may be expected that in these locations (noted as PP on the Creek 02 section in **Appendix A**), that an increased of pooling of water may result from the predicted mining subsidence.

The Creek 03 section in **Appendix A** shows that swamp 15b will undergo minor grade changes in the order of 1%. Points of potential increases or decreases to pooling are shown on the plan. The more minor nature of grade changes in swamp 15b is due to the orientation of the swamp along longwall 8 (rather than across several longwalls) which means the swamp lies across only one subsidence trough. Refer to the section layout plan in **Appendix A**.

It should be noted that the zones of maximum grade increase or decrease tend to occur in relatively small distances of less than 50m, and that these areas correspond to the sides of the predicted subsidence trough above the proposed longwalls.

It should also be noted that the MSEC subsidence predictions are conservative and usually over predict the actual measured subsidence, so the gradient changes presented may be viewed as an *upper bound* of what may be expected.

Based on the future longwalls in Areas 3B and 3C having similar void widths, chain pillar widths and extraction heights to those in Area 3A, the maximum predicted systematic subsidence parameters resulting from the extraction of the future longwalls in these areas are expected to be similar to those predicted for Longwalls 6 to 10 in Area 3A.

Based on this assessment, and that of MSEC's then, we can conclude that the swamps and watercourses undermined by proposed and future longwalls in Area 3 may be subjected to gradient changes of up to approximately 2.1%. (ie. The maximum predicted for Area 3A).

Impacts of Predicted Gradient Changes on Swamps

MSEC have noted the predicted differential total subsidence and total tilt within Swamps located above longwalls may result in increased water levels above the centrelines of the longwalls, and decreased water levels above the chain pillars and longwall goaf edges.

It is possible that minor changes in water level within the swamps could impact on the distribution of local vegetation within the swamps. Generally, however, the surfaces of the swamps are free draining, and it is not anticipated that significant changes in ponding would occur as a result of differential subsidence or tilt.

It is noted that the *maximum grade change predicted (in Area 3A) of 2.1%* is less than the average grade of all swamps in Area 3, except swamp 2. We note again that the *average* swamp gradient varies from a minimum of 1.6% (Swamp 2) up to a maximum of 16.3% (Swamp 34). Refer **Table 4.3**. The overall average swamp gradient for all swamps within Area 3 is 5.1%. Approximately 90% of the swamps have average swamp gradients within the range of 2.2-8.1%.

The maximum swamp gradient varies significantly from a minimum of 5.9% (northern section of Swamp 6) up to a maximum of 66.7% (Swamp 15a). Refer **Table 4.3**. The average maximum swamp gradient is 16.2%. Approximately 80% of the swamps within Area 3 have maximum gradients of less than 30%.

Therefore, in general, any mining induced gradient change will be less then the average grade of the swamp and is insignificant in comparison to the natural grade variations observed in these swamps.

The creek sections provided in of **Appendix A** do note that within any swamp oriented across longwalls that areas of increased grade and decreased grade will occur, and that depending on the natural grade of the swamp, this could result in slightly increased flow velocities over that small section of swamp, or increased pooling if the gradient decrease is greater than the grade at that section of swamp/watercourse. The relative change will be greater in flatter swamps/watercourses.

Where decreased grade changes are a similar order of magnitude to the existing natural grades, slightly increased levels of ponding and flooding may result. Where the bed control is exposed alluvial sediment (rather than bedrock) and not stabilised by vegetation, we might expect some scour of the pooled area to occur in high flows until equilibrium within that reach is achieved.

Due to the inherent stability of the majority of swamps within Area 3 (discussed in detail in the following sections and outlined in **Table 4.3**) we believe that grade increases will not ordinarily lead to increased scour and erosion episodes unless surface cracking or other surface disturbance exist in the flow path, from which scour can be initiated. In some cases where the bed control is exposed alluvial sediment and not stabilised by vegetation, we might expect some scour to occur until equilibrium within that reach is achieved.

The effect of Catchment Slope on Velocity and Lag time

Intuitively it might be thought that catchments and streams with steeper slopes would have higher mean flow velocities and consequently lower lag times. This reasoning comes from Manning's equation in which velocity is proportional to slope $S^{1/2}$ indicating that travel times are proportional to $L/S^{1/2}$ and this form was used in many early equations for lag or travel time.

Manning's Equation:

$$V = \frac{R^{2/3} S^{1/2}}{n}$$

However Boyd et al (2006) found that generally, slope does not have any significant effect on lag times. Studies of travel times and flow velocities in streams (Leopold et al 1964, Pilgrim

1977, 1982) show that velocities remain relatively constant along a stream, both in the steeper headwaters and in the flatter lower reaches. An explanation for this is that when moving downstream along a stream, the decrease in slope is compensated by an increase in depth and hence in hydraulic radius. These studies therefore indicate that slope is not a dominant factor in determining lag times.

Boyd et al (2006) cites evidence that clearly indicates that, rather than flow velocities decreasing in moving from the steeper headwaters to the flatter slopes near the catchment outlet, they remain essentially constant or even increase slightly in moving downstream.

Boyd et al (2006) determined that overall, there was no strong trend for lag (and velocity) to vary with catchment slope, over a wide range of slopes and that a review of studies on the variation of flow velocity within catchments, and the variation of lag times between different catchments, supports these results.

It is worth noting that hydrologic models such as WBNM and most current applications of RORB allocate lag times to the sub catchments within the larger catchment using stream lengths and *not* stream slopes in the relevant equations. The lag equations within the WBNM hydrologic model include the effect of area (A) and discharge (Q), but do not include the catchment slope (S). This is because the studies of lag times on natural catchments by Askew (1968, 1970) found that catchment slope was not a significant factor. The catchment area is certainly the dominant influence on lag time (and velocity), with other factors such as slope or catchment shape being secondary, or not significant at all. It is worth noting that some other studies and other models include (S) in the lag relation, but always as a secondary variable, after area (A).

Boyd et al (2006) also noted that tracing studies of Pilgrim [1976, 1977, 1982], showed flow velocities in the main stream channels of catchments were found to be on average twice those than in smaller drainage lines.

Sensitivity Analysis of Gradient Change in Swamp 15a

A sensitivity analysis was carried out for a point near that of maximum gradient increase in Swamp 15a over longwall 10 to estimate the increase in flow velocity that may occur as a result of an increase in gradient of 2.1% (the maximum predicted increase in swamp flow gradient for area 3A). The point on Swamp 15a has been conservatively chosen because its initial gradient is close to level (0.015%) and flow velocities at this point would therefore be more sensitive to changes in gradient.

The flow velocities were calculated for pre and post mining using manning's equation and stream flows obtained from WBNM modelling of the swamp catchments. The results are summarised in **Table 4.4**. Flow velocities for the existing gradient of 0.15% were estimated to be 0.12 m/s, 0.40 m/s, and 0.44 m/s for the 2yr ARI 2hr duration, 50yr ARI 2hr duration, and 100yr ARI 2hr duration storms respectively. When the gradient at this point was increased from a grade of 0.15% (by a magnitude 2.1%) to a grade of 2.25%, the flow velocities were calculated to be 0.26m/s, 0.90 m/s, and 0.98 m/s for the 2 yr ARI 2hr duration, 50yr ARI 2hr duration and 100yr ARI 2hr duration storms respectively. In each case the estimated velocity increase *at that point* is calculate to be within the range of 115-125%.

The manning's roughness coefficient has a significant influence on calculated flow velocity and is also highly variable with flow depth. In the case of the 2yr ARI 2hr duration storm the flow depth was relatively low (maximum flow depth of approx. 0.6-0.8m) and hence a higher mannings value of 0.15 was used. When the flow depth is increased, vegetation in the channel bed is generally flattened and hence the mannings roughness is significantly reduced. The flow depth for both the 50 and 100yr ARI 2 hr duration storms was greater than 1m and hence a mannings value of 0.06 was used for these storms. (Calculations are attached in **Appendix B**).

Table 4.4 - Pre and Post Mining Flow Velocities near the Point of Maximum Predicted Gradient Change over Longwall 10

ARI (yrs)	Mannings Value Used	Pre-mining Flow Velocity (0.15% gradient)	Post-mining Flow Velocity (2.25% gradient)	Increase in Flow Velocity at that point
2	0.15	0.12 m/s	0.26 m/s	117%
50	0.06	0.40 m/s	0.90 m/s	125%
100	0.06	0.44 m/s	0.98 m/s	123%

It is noted that although the relative increase in velocity at this point is large (approx. 120%), the overall maximum velocity is quite low with respect to scour potential and the estimated maximum flow velocity of 0.98 m/s for the 100yr ARI 2hr duration storm is still well below the value of 2.2 m/s determined by EarthTech (2005) to be the velocity above which the initiation of scour within these swamps is expected to occur.

It is also noted that this estimated maximum velocity would only be represented for a relatively short period of time at the peak of the storm hydrograph and would not occur for a sustained period. It is understood that the major controlling factor in stream geomorphology is the relative *frequency* of storm events rather that the specific flow conditions at the time of maximum flow for any particular storm.

Since the zones of maximum gradient change extend for very short distances (eg. Less than 20 metres) and the actual mean gradients of the subsidence affected swamps change very little, we conclude that any mean velocity changes in watercourses and swamps would be likely to be imperceptible. This is supported by the research outlined above on the effect of Catchment Slope on Velocity.

Based on the gradient assessment undertaken, together with the previous detailed research, we conclude that localised increases in gradient associated with subsidence will not lead to significant increases in velocity that would increase shear thresholds and result in a significant increase of scour potential in swamps or watercourses within Area 3.

4.3.5. Vegetation Cover

Vegetation cover was determined by reference to the recent IC “Understanding Swamp Conditions” inspection report (2007) and Earthtech (2003) report in addition to visual inspection of swamps 12,15a and 15b.

Vegetation cover for each swamp in Area 3 is outlined in **Table 4.3.**

The majority of the swamps that lie within the proposed Area 3 footprint are well vegetated with little or no poorly vegetated areas. Inspections were initiated by IC at 15 of the 23 swamps that lie within Area 3 during winter 2006 and summer 2007 and signs of prior vegetation stress were noted at only 5 of the 15 swamps inspected. Swamps for which signs of possible vegetation stress were observed included:

- Swamp 10 – Minor yellowing of *Glichenia dicarpa* observed during the inspection of winter 2006. This may indicate vegetation stress after prolonged drought periods.
- Swamp 11 – Minor yellowing of vegetation stress was noted during the winter 2006 and summer 2007 inspections.
- Swamp 15a – Some yellowing of vegetation noted on sedges and low lying vegetation on the swamp margins during the winter 2006 and summer 2007 inspections.
- Swamp 15b – Some yellowing of *Glichenia dicarpa* in the northern edge of the swamp and fire scars with minimum vegetation coverage on the southern margin of the swamp were observed during the winter 2006 inspection.
- Swamp 23 – Vegetation was found to be healthy with remnant stands of burnt *Banksia Ericifolia* observed throughout swamp during the winter 2006 inspection.

In summary, IC swamp surveys have determined the vegetation cover for the majority of swamps within Area 3 is very good with only one swamp (swamp 15b) showing signs of fire scalds which have caused a persisting disturbance to vegetation cover on the southern fringe of that swamp.

4.3.6. Soil Landscape Type and Erosion Hazard

This information was sourced from “Soil Landscapes of the Sydney Catchment Authority's (SCA) hydrological catchments” Version 2 (2006). It was compiled from January 2001 to June 2002 as part of a project to map the Soil Landscapes for the entirety of the Sydney Catchment Authority's (SCA) hydrological catchments.

Soil Surveying was conducted by the former NSW Department of Land and Water Conservation (DLWC) Soil Surveyors, present day NSW Department of Natural Resources (DNR).

Soil Surveyors use numerous other resources in order to delineate soil landscape boundaries, such as air photos, geological surveys, radiometrics, satellite imagery and vegetation surveys. Local knowledge is also sought from landholders, community groups and land managers.

The 1:100,000 Soil Landscape maps are prepared on 1:25,000 base sheets. Soil Landscape delineations of less than 20ha are generally not mapped unless locally significant.

This more recent report substantially revises the mapping of the older 1:100,000 sheet that accompanied Hazelton and Tille (1990), and in particular the erodibility and dispersibility classification of many soil landscapes in the SCA Special Areas have been substantially upgraded in the Dewar et al. (1996) vs. Hazelton and Tille (1990).

Figure 3.4 below provides a soil landscape plan of Area 3. The legend identifies the five major soil landscape types which appear in Area 3 as described in “Soil Landscapes of the Sydney Catchment Authority's (SCA) hydrological catchments” Version 2 (2006) being the:

1. Penrose Variant A (code ERpea) type developed on the moderately steeper 10 – 20% slopes of Hawkesbury Sandstone;
2. Hawkesbury (code COha) type developed on very steep slopes of Hawkesbury Sandstone of greater than 25% within creek main valleys and lower sections of tributaries;

3. Lucas Heights (code REh) developed on gentle undulating crests, ridges and plateaus of slope <10% on Wianamatta Shale or Mittagong Formation (the latter being a thin mixed sandstone/shale sequence lying between the Wianamatta Shales and Hawkesbury Sandstone) derived soils;
4. Gymea (code ERgy) developed on Hawkesbury Sandstone undulating to rolling low hills with local relief 20 – 80 m and moderately steep slopes of 10 – 25%; and
5. Stockyard Swamp (code SWss) developed on flat low relief areas of Hawkesbury Sandstone of slopes generally <2%.

The legend of **Figure 3.4** also identifies the concentrated flow erosion hazard for each landscape which partly reflect the slope gradients on which the landscape is formed.

These are:

- Penrose Variant A (erosion hazard moderate to high)
- Hawkesbury (erosion hazard extreme)
- Lucas Heights (erosion hazard moderate)
- Gymea (erosion hazard high to extreme)
- Stockyard Swamp (erosion hazard moderate to high)

It should be noted that Soil Landscape delineations of less than 20ha are generally not mapped unless locally significant, and it appears that some areas that could perhaps be classified as stockyard swamp have not been identified.

Table 4.5 below outlines the number of swamps in Area 3 that occupy each soil landscape and **Table 4.3** outlines the soil landscape occupied by each swamp. It is noted that some swamps cover multiple soil landscape types and are therefore accounted for in more than one of the rows in **Table 4.5.**

Table 4.5 - Number of Swamps in Each Different Soil Landscape Type

Soil Landscape Type	Concentrated Flow Erosion Hazard	No. of Swamps Located on Soil Landscape Type
Lucas Heights	Moderate	6
Penrose Variant A	Moderate-High	12
Stockyard Swamp	Moderate-High	11
Gymea	High-Extreme	3

The majority of swamps occur on soil landscapes with moderate to high erosion hazards, while watercourses within Area 3 occurred on all soil landscapes and often flow through several soil landscape categories.
Only swamp 12 occurs on the Gymea soil landscape associated with an extreme erosion hazard and therefore may be considered at most risk from any potential scour events based on this risk factor. However, this swamp is located in the headwaters of the catchment and is not particularly large.

4.3.7. Swamps Oriented Across Longwalls

In their 2005 report on Thresholds for swamp stability, EarthTech (2005) identified a number of orientation characteristics which may put a swamp or watercourse at more risk of potential scour occurring due to mine subsidence. EarthTech contended that:

- Swamps contained wholly within a single longwall or running parallel to the longwall orientation are only susceptible to the effect of subsidence over the time that and the adjacent longwalls are being mined.
- Conversely, swamps overlying more than one longwall, such as is often the case when the longwalls are orientated at right angles to the swamp, are subject to subsidence over the period of mining all underlying and adjacent longwalls. As longwall operations progress, the depth of subsidence progressively increases until the maximum depth is reached.

Therefore, swamps contained wholly within a longwall are at a lower risk of the effects of subsidence than swamps that overly more than one longwall.

EarthTech noted the drainage lines of the Woronora Plateau are typically either swamps or bedrock controlled watercourses. If a swamp lies wholly within a longwall subsidence trough (i.e. not across the subsidence perimeter), the maximum point of increased grade will not be located in the swamp at completion of operations but on a bedrock controlled creek. As a consequence there is low likelihood of further incision.

EarthTech concluded that:

- If the upstream end of a swamp lies on or extends beyond the perimeter of the mine subsidence trough, the swamp will continue to have a *higher potential* to scour beyond the life of the mine and beyond the upstream limit of increase in grade until a correcting event such as channel deepening occurs.
- If the downstream end of the swamp lies on or extends beyond the mine subsidence perimeter, water has the potential to pool in the swamp/watercourse and no incision is likely to occur.

We have therefore considered these issues as part of our assessment.

Figure 4.1 shows that swamp 12 and 15a lie across the proposed longwalls in Area 3A. Swamp 15b is oriented generally along Longwall 8 however it meanders across the subsidence trough on the northern side and will be subjected a range of gradient changes.

As mining plans for Areas 3B and 3C have not yet been determined, we cannot accurately assess the orientation of swamps in these areas compared to longwalls. To ensure the impact assessment is conservative, this study assumed that the swamps and minor watercourses in Areas 3B and 3C *will lie across* longwalls (as occurs for 2 out of three swamps in area 3A). Due to this likely orientation across subsidence troughs, we conclude that swamps and watercourses in Areas 3A, 3B and 3C will be likely to undergo the landscape impact of minor gradient changes as a result of mine subsidence.

Where minor gradient increases occur, the swamp or watercourse could be considered to have a *higher potential* to scour beyond the life of the mine and beyond the upstream limit of increase in grade until a correcting event such as channel deepening occurs. However, as many swamp drainage paths and watercourses are actually bedrock controlled, this higher potential to scour is considered to be very minor where these bedrock controls occur. Refer

Table 4.3, which shows that many of the swamps in Area 3 are bedrock controlled along parts of their main flowpath. Furthermore, both our impact assessment of gradient changes above in relation to velocity/ shear strength, and EarthTech's hydraulic assessment of shear stress thresholds (2005) in Woronora plateau swamps demonstrate, that even where a swamp or watercourse is subject to a minor increase in gradient change, the resultant scour potential increase is minimal.

Where minor gradient decreases occur, water has the potential to pool in the swamp/watercourse and no incision is likely to occur. As described above and shown in the relevant figures, the nature of pooling is relatively minor is not expected to result in any significant impacts other than perhaps a redistribution of vegetation in the immediate area due to increased moisture.

In summary then, as the majority of swamps and watercourses in Area 3 will lie across longwalls, and their respective subsidence troughs, we conclude that these swamps and watercourses will be likely to undergo the landscape impact of minor gradient changes as a result of mine subsidence. Although there is a *higher potential* to scour where minor gradient increases occur, these changes are unlikely to result in increased scour events due to a minimal increases on actual shear strengths over different flow events, the inherent stability of the swamps due to good vegetation cover, the occurrence of bedrock as a control in some cases, and the lack of defined concentrated flow paths in other cases.

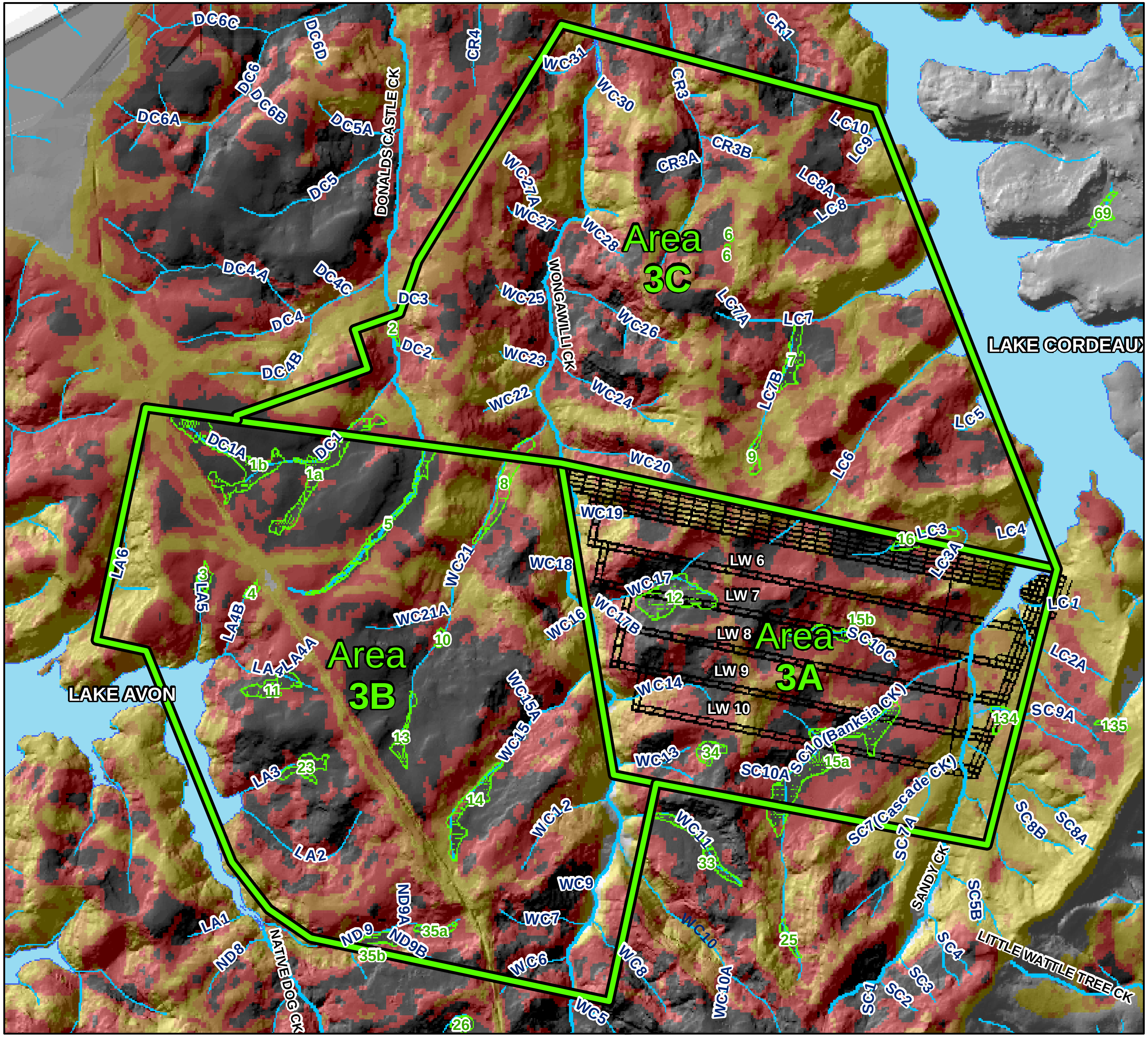
4.3.8. Fire History

Fire History & Climatic Events were determined by reference to recorded SCA data of such events previously referred to by Earthtech (2005).

A major bush fire occurred in the region between December 24th 2001 and January 22nd 2002. Extent and severity of the 2001/02 fires was available in map form from the SCA and has been reproduced below as **Figure 4.3.**

The fires burnt much of the bushland in the region of the proposed Dendrobium Area 3. Most swamps examined in the Dendrobium mining areas were classified as having been burnt to an extreme extent or high extent, with a few being burnt to a medium extent. This extreme and high severity burning was not restricted to the swamps but affected large areas where most of the swamps are situated.

However, recent inspections of the swamps by IC in 2006 & 2007 show that only swamp 15b shows evidence of minor fire scarring on its southern margin, which is not subject to any concentrated flows, and has been stable since 2002. Hence the swamps throughout Area 3 have very good vegetation cover and soil protection.



bhpbilliton
ILLAWARRA COAL

Fire Severity Map of 2001/2002 Bushfires

DENDROBIUM AREA 3

Legend

- Creeks & Rivers (LPI)
- Minor Streams
- Lakes (LPI)
- Swamps
- Proposed Longwall Layouts
- Proposed Area 3 Footprint

Fire Intensity (SCA)

- 5 - Extreme
- 4 - High
- 3 - Moderate
- 2 - Low
- 1 - Not Burnt

®

FIGURE 4.3

Scale 1:40,00 (at A4)

Kilometres
0 0.25 0.5 1 1.5 2

Cardno
Forbes Rigby

Map Produced by Forbes Rigby Pty Ltd
Date: 11 October 2007
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF:
107055-02_2820_Fire_severity_plan.mxd

4.3.9. Existing Points of Disturbance

Existing Points of disturbance within swamps and watercourses in Area 3 were determined by reference to the recent IC "Understanding Swamp Conditions" inspection reports (2007) and Earthtech reports in addition to visual inspection of swamps 12,15a and 15b.

Monitoring by IC and EarthTech indicates the only swamps with any existing points of disturbance (nick points) where scour may be expected to be initiated are a couple of small sections of slightly scoured (but stable) channel in swamp 5 (Luke Pascot pers comm) and a section of channel within swamp 8 that has been recently incised and scoured (EarthTech 2005).

It is noted both these swamps are long linear valley floor swamps with relatively large catchment areas, and have been formed from fluvial processes such as erosion and deposition. Therefore, it would be expected that these swamps may show existing signs of such processes.

In summary however, as a whole, the swamps in Area 3 have been observed to be remarkably stable with the vast majority showing no obvious existing scour locations that put them at additional risk from the proposed mining.

4.3.10. Overall Risk of Increased Scour within Swamps and their Watercourses

The analysis has assessed a range of risk factors within swamps and their respective watercourses that have increased our understanding about the relative risk of scour within these systems in a pre-mining and post-mining context.

We have assessed that recent survey and reporting indicates that the swamps within Area 3 are in good condition and that minor, mining induced gradient changes are not expected to result in any velocity increases that would result in significant increases in scouring episodes.

Despite experiencing fires in 2001/02, the vegetation has recovered very well, which has kept the swamps relatively stable in a geomorphological sense. It is suspected that the stability of the swamps is at least partly attributable to an ongoing source of groundwater, which Ecoengineers (2007) have attributed to be the product of shallow hillslope aquifers.

Considering all the identified risk factors then, we assess the risk of increased scour from the mining induced landscape impacts as being low. The swamps at most risk of scour are the valley floor swamps with the largest catchment areas that are formed on the central drainage line, and that have evidence of existing scour. These are Swamp 8 and to a lesser extent, swamp 5.

4.3.11. Hydrologic and Water Quality Impacts

Given that the landscape related impacts described above are assessed as being minor, the primary question that remains is whether subsidence induced tensile and compressive cracking of bedrock below and around swamps is likely to lead to:

- significant impacts on swamp hydrology (via significant water loss/increase or change in water retention characteristics) and water quality;

- and whether hydrologic and water quality impacts are likely to result in significant ecological impacts.

Recently, work by IC and Ecoengineers (Ecoengineers 2006, Ecoengineers 2007) have questioned the current understanding of hydrology in upland swamps, in particular the common perception that they are typically found on the floors of low gradient valleys on impermeable substrates in high-rainfall catchments.

Firstly, Ecoengineers point out that most swamps in this area have considerable gradients. They also note that quantitative water balance studies have never been published on any Woronora Plateau upland swamps to validate the entrenched view of an impermeable substrate.

Ecoengineers (2007) note the subject swamps are located in terrain subjected to numerous wet glacial and dry interglacial cycles throughout the Pleistocene and far wetter conditions in the late Pliocene. Consequently the Hawkesbury Sandstone bedrock in which they lie is not expected to be hydraulically 'tight' (impermeable) but deeply weathered and relatively permeable to depths substantially greater than the depths of the swamps.

The excess of precipitation over evapotranspiration (ET) which proportionally sustains these swamps (Hatton and Evans, 1998) is suspected to be due to a significant fraction of precipitation penetrating to depths of over 2 m into the underlying weathered sandstone of the Plateau too quickly to be subject to ET (Thyer and Kuczera, 2000).

The concept of a hillslope aquifer well elevated above the draining stream in weathered Hawkesbury Sandstone terrain has been validated by non-linear parameter optimization hydrologic modelling in early 2006 of the recession of large storm events in the nearby Native Dog and Donald's Castle Creek Catchments (Ecoengineers 2006). Ecoengineers contend that many of the swamps in Area 3 can be described as Groundwater Dependent Ecosystems sitting in a more broadly-based long term shallow aquifer system upon which they are dependent for their observed long term stability.

In relation to subsidence induced hydrologic, water quality and ecological impacts on upland swamps in the Woronora plateau, Ecoengineers have identified that:

1) Young (1977) found out the margins of the Woronora upland swamps did not change at all in high resolution aerial photographs between 1951 and 1977. These observations of long term margin stability have been replicated many times since (e.g. Mooney, 1994).

2) Adverse hydrologic effects e.g. broad or even discrete zones of desiccation in well vegetated upland swamps which have been subject to mining induced subsidence have not been detected anywhere in the Woronora Plateau over 10 years of study, a period encompassing 6 years of drought and several major wild fires. This includes recently undermined swamps at Eloeura Colliery.

3) Extensive water quality monitoring within and immediately downstream of swamps over almost 5 years of study has not detected any geochemical effects from mining subsidence beneath or immediately downgradient of swamps which would be indicative of the cracking of a 'tight' impermeable sandstone bedrock containing unweathered marcasite.

Ecoengineers (2007) note fracturing due to subsidence effects might sometimes become physically detectable at a central drainage line rock shelf or knick points in headwater/valley side swamps, but contend that such fracturing should be confined to sandstone that already contain, naturally, well weathered bedding planes and cross fractures due to the long period of exposure of such features and thus further fracturing should be inconsequential. Hydrologic and/or geochemical effects on this type of swamp from longwall mining are only likely to be significant where longwall mining subsidence-related effects have induced some significant change, not so much to an individual rock shelf or knick point as this will have no significant geochemical or ecological effect on the upgradient or down gradient portions of the swamp, but to a broad scale hillslope aquifer. Detection of change requires deployment of a network of shallow piezometers within and outside of swamps to gauge changes in the extent and/or vertical thickness of the hillslope aquifer(s) over the proposed or active longwalls.

Ecoengineers (2007) consider it unlikely on the basis of past experience that mine subsidence-induced hydrologic effects would adversely affect these swamps and more particularly the substantial hill slope aquifers in which they are likely to be embedded.

We note there is a paucity in long term swamp water balance data from undermined swamps, and rigorous pre and post mining ecological surveys. However, based on the available information, we conclude that there is currently little evidence to indicate the proposed mining will have a significant impact on the subject swamps.

We recommend detailed monitoring commence and acknowledge there are multiple shallow borehole monitoring points recently installed in Area 2 and 3, as outlined in the Dendrobium Area 3A SMP.

4.4. WATERCOURSES AND SWAMPS AT GREATEST POTENTIAL RISK

The characteristics of each swamp in Area 3 provided in **Table 4.3** have been discussed in section 4.3 in respect to the risk of impacts due to mining induced subsidence.

4.4.1. Swamps/Watercourses At Most Risk Of Catchment Change

Swamps at risk of hydrological changes due to mine subsidence induced changes to the catchment area or watershed were assessed in section 4.3.2.

Detailed analysis has predicted no catchment change for Area 3A The subcatchments in Area 3B and 3C will need detailed investigation once the mine layout is defined to confirm there are no catchment changes for swamps such as 1b, 1a, 4, 5 and 13, which appear to be the most susceptible to any such change.

4.4.2. Swamps/Watercourses At Most Risk Of Scour

In summary, as we must assume in the absence of defined mine layout for areas 3B and 3C that the majority of swamps and minor watercourses in Area 3 *will lie across* longwalls (as for Area 3A), and their respective subsidence troughs, we conclude that these swamps and watercourses will be likely to undergo the landscape impact of minor gradient changes as a result of mine subsidence. Although there is a *higher potential* to scour where minor gradient increases occur, these changes are unlikely to result in increased scour events due to a minimal increases on velocities and actual shear strengths over different flow events, the occurrence of bedrock as a control in some cases, and the lack of defined concentrated flow paths in other cases.

Where minor gradient decreases occur, water has the potential to pool in the swamp/watercourse and no incision is likely to occur. The nature of pooling is relatively minor is not expected to result in any significant impacts other than perhaps a redistribution of vegetation in the immediate area due to increased moisture.

We have determined that by referring to **Figure 4.2**, the stream order and catchment areas noted in **Table 4.3,** that within Area 3 as a whole, Swamps 2, 5, 7, 8 and 15a appear to be the swamps at *most potential risk* of undergoing scour due to their downstream location on the drainage channel, large catchment area, and therefore magnitude of flows that may be expected in large rain events. These swamps are shown on **Figure 4.4** as the swamps and watercourses at *most potential risk* of undergoing scour.

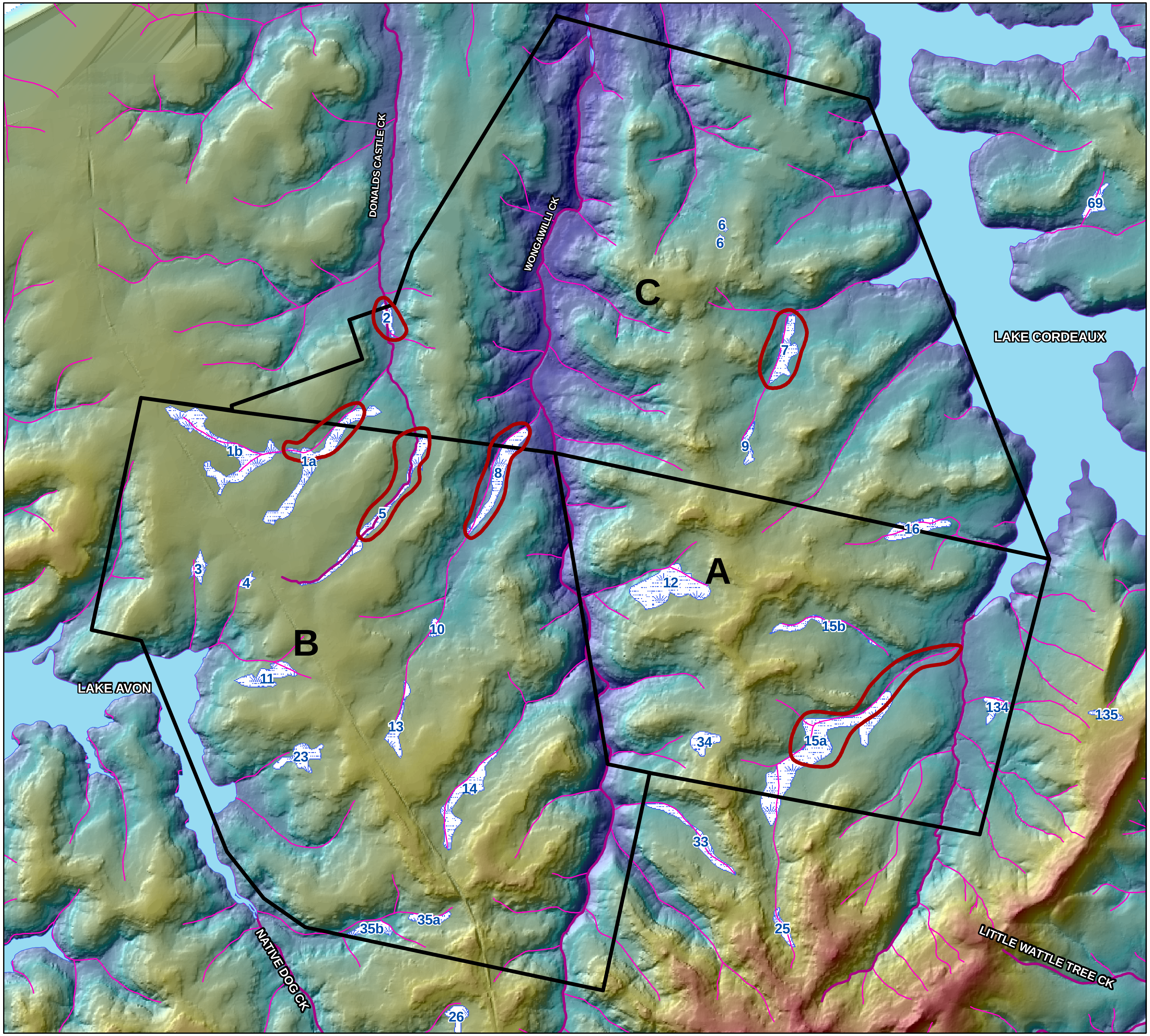
Furthermore, monitoring by IC and EarthTech indicates the only swamps with any notable existing points of disturbance (nick points) where scour may currently be expected to be initiated are a couple of small sections of slightly scoured (but stable) channel in swamp 5 (Luke Pascot pers comm) and a section of channel within swamp 8 that has been recently incised and scoured (EarthTech 2005).

For the swamps 12,15a and 15b in Area 3A where more detailed analysis of the predicted post subsidence DTM has been undertaken, it is apparent that due to it's large catchment area, considerable length, orientation over the subsidence perimeter and longwalls 9 & 10, in addition to it's relatively flat grades over significant sections, that swamp 15a is considered the swamp at most risk of any potential mine induced subsidence impacts.

The Creek 03 Section in **Appendix A** shows that there are several locations of predicted gradient change along 15a, and that the interaction of these with the large flows generated by the catchment pose the greatest potential risks within Area 3A.

While sections of swamps 12 and 15b (Sheet 3 & 5 of **Appendix A)** also show that there are several locations of predicted gradient change, the average grade of these creeks is considerably more than that of 15a, while their slope lengths are approximately half of, and their catchments are approximately one third of swamp 15a.

It is recommended theses swamps are visually monitored along their lengths where undermined, with special attention to their flow paths in areas where gradient change is predicted, as outlined in section 5 below.



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Swamps and Watercourses at most potential risk of increased scour

DENDROBIUM AREA 3

- Proposed Area 3 Footprint
- Lakes
- Rivers
- Creeks
- Minor Streams
- Swamps
- Swamps and watercourses at most potential risk of increased scour

Elevation:

- 500 - 550m
- 450 - 500m
- 425 - 450m
- 400 - 425m
- 350 - 400m
- 275 - 300m

N
W
E
S

FIGURE 4.4

Scale 1:27,500 (at A3)

Metres

0 250 500 1,000 1,500

Cardno Forbes Rigby

Map Produced by Forbes Rigby Pty Ltd
Date:13 September 2007
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF:
107055_02_2817_Swamps_at_risk.mxd

5. PROPOSED MONITORING LOCATIONS FOR AREA 3A

5.1. SITE SELECTION FOR MONITORING LOCATIONS

Proposed Monitoring Sites in Area 3A were identified from the locations determined by the assessment to be at greatest risk of experiencing landscape impacts such as rock falls, soil cracking/slippage and strata dilation/buckling and gradient changes within watercourses/ swamps. These locations were summarised in sections 3.4 and 4.4.

A subsidence landscape monitoring and management program (SLMMP) for the landscape elements of Dendrobium Area 1 was prepared by GSS in November 2004. This plan has been subsequently modified to include Area 2 and the revised document was incorporated into the Subsidence Management Plan (SMP) prepared for Area 2 in accordance with the DPIM guidelines.

The preparation of further documentation to detail the landscape monitoring and management to be undertaken for Area 3 is required to fulfil the requirements of both the Consent and the SMP Guidelines. The revised Area 3A SMP fulfils that requirement. Refer **Table 5.1** which summarises the proposed Landscape Monitoring Schedule.

For Area 3, baseline monitoring will occur the year prior to mining commencing using established methods. As mining in Area 3 is projected to be commence January 2010, baseline monitoring and reporting will occur in 2009.

The plan will be the subject of review through consultation with the various stakeholders associated with the Dendrobium Colliery. This process will address any feedback provided by stakeholders.

Table 5.1 - Summary of Landscape Monitoring Schedule

Environmental Aspect	Pre-Mining Baseline Survey Frequency	Monitoring Frequency During Mining	Monitoring Frequency Post-Mining	Persons Responsible
Cliffs	Twice	All Sites 6 Monthly &	6 Monthly for two years after mining	Environmental Consultant
Steep Slopes	(Months apart)	Individual Sites Monthly During Active Subsidence		
Watercourses		**And in response to third party observations, where necessary.**		
Firetrail				
Land Capability	Once	None	Once, two years after mining	Environmental Consultant

5.2. SITE SELECTION FOR SWAMPS AND WATERCOURSES

The various proposed monitoring sites are shown in **Figure 5.1** and are described below.

Cliffs

A3-CL1 – The entire length of the central cliff line identified by MSEC has been selected for monitoring (from MGA *X 292987.855 Y 6192094.911* to *X 293008.826 Y 6192106.480*). The monitoring area is approximately 25m and represents one of the significant cliff areas in Area 3.

A3-CL2 -The entire length of the central cliff line identified by MSEC has been selected for monitoring (from MGA *X 292809.617 Y 6192108.220* to *X 292829.866 Y 6192102.070*). The monitoring area is approximately 25m and represents one of the significant cliff areas in Area 3.

A3-CL3 -The entire length of the central cliff line identified by MSEC has been selected for monitoring (from MGA *X 291252.821 Y 6192295.045* to *X 291306.241 Y 6192294.563*). The monitoring area is approximately 100m and represents one of the significant cliff areas in Area 3.

A3-CL4 -The entire length of the central cliff line identified by MSEC has been selected for monitoring (from MGA *X 291282.478 Y 6192392.20*3 to *X 291341.086 Y 6192371.607*). The monitoring area is approximately 100m and represents one of the significant cliff areas in Area 3.

A3-CL5 -The entire length of the central cliff line identified by MSEC has been selected for monitoring (from MGA *X 291141.061 Y 6192542.529* to *X 291161.907 Y 6192489.112*). The monitoring area is approximately 100m and represents one of the significant cliff areas in Area 3.

Steep Slopes

A3-SL1 – A length of approximately 150m length of steep slope will be monitored (from MGA *X 293177.217 Y 6193027.588* to *X 293331.159 Y 6193024.278*). A steep slope quadrat (20m X 20m) will be located above Longwall 6 to the eastern end of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

A3-SL2 – A length of approximately 75m length of steep slope will be monitored (from MGA *X 293548.002 Y 6192934.892* to *X 293609.248 Y 6192992.827*). A steep slope quadrat (20m X 20m) will be located above Longwall 6 to the southeastern end of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

A3-SL3 – A length of approximately 450m length of steep slope will be monitored (from MGA *X 291100.013 Y 6193153.132* to *X 291557.678 Y 6193272.917*). A steep slope quadrat (20m X 20m) will be located above Longwall 7 to the western end of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

A3-SL4 – A length of approximately 175m length of steep slope will be monitored (from MGA *X 292299.898 Y 6192906.826* to *X 292460.262 Y 6192912.878*). A steep slope quadrat (20m X 20m) will be located above Longwall 7 in the middle of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

A3-SL5 – A length of approximately 100m length of steep slope will be monitored (from MGA *X 292126.369 Y 6192614.666* to *X 292168.326 Y 6192711.490*). A steep slope quadrat (20m X 20m) will be located above Longwall 8 in the middle of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

A3-SL6 – A length of approximately 175m length of steep slope will be monitored (from MGA *X 293163.975 Y 6192648.527* to *X 293312.951 Y 6192572.384*). A steep slope quadrat (20m X 20m) will be located above Longwall 8 to the eastern end of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

A3-SL7 – A length of approximately 100m length of steep slope will be monitored (from MGA *X 291561.846 Y 6192596.357* to *X 291653.534 Y 6192640.149*). A steep slope quadrat (20m X 20m) will be located above Longwall 9 to the western end of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

A3-SL8 – A length of approximately 150m length of steep slope will be monitored (from MGA *X 292250.195 Y 6192291.185* to *X 292388.412 Y 6192356.872*). A steep slope quadrat (20m X 20m) will be located above Longwall 9 in the middle end of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

A3-SL9 – A length of approximately 175m length of steep slope will be monitored (from MGA *X 291401.117 Y 6192412.646* to *X 291590.822 Y 6192386.121*). A steep slope quadrat (20m X 20m) will be located above Longwall 10 to the northwestern end of Panel (coordinates to be determined during baseline monitoring). This site is within the steep slope area identified by MSEC.

Watercourses/Swamps

A3-WC1- A length of approximately 700m length of watercourse and swamp will be monitored (from MGA *X 291885.010 Y 6193028.257* to *X 291256.019 Y 6193043.028*). This watercourse is above Longwall 7 and above the northwestern boundary of Longwall 8 and is feed by a creek/swamp located on top of longwall 7 and 8. Is also the first creek to be mined underneath and it is the largest creek above Longwall 8.

A3-WC2- A length of approximately 1000m length of watercourse and swamp area will be monitored (from MGA *X 292447.632 Y 6192738.821* to *X 293256.265 Y 6192495.863*). This watercourse and creek/swamp is above Longwall 8 and above the boundary of Longwall 7. It is the smallest creek/swamp to be mined under Longwall 8.

A3-WC3- A length of approximately 1325m length of watercourse and swamp area will be monitored (from MGA *X 292663.646 Y 6191872.880* to *X 293817.777 Y 6192591.084*). This watercourse is above Longwall 8, 9, 10 and is feed by the creek/swamp that is situated above longwall 9 and 10. This is the longest watercourse/swamp to be monitored.

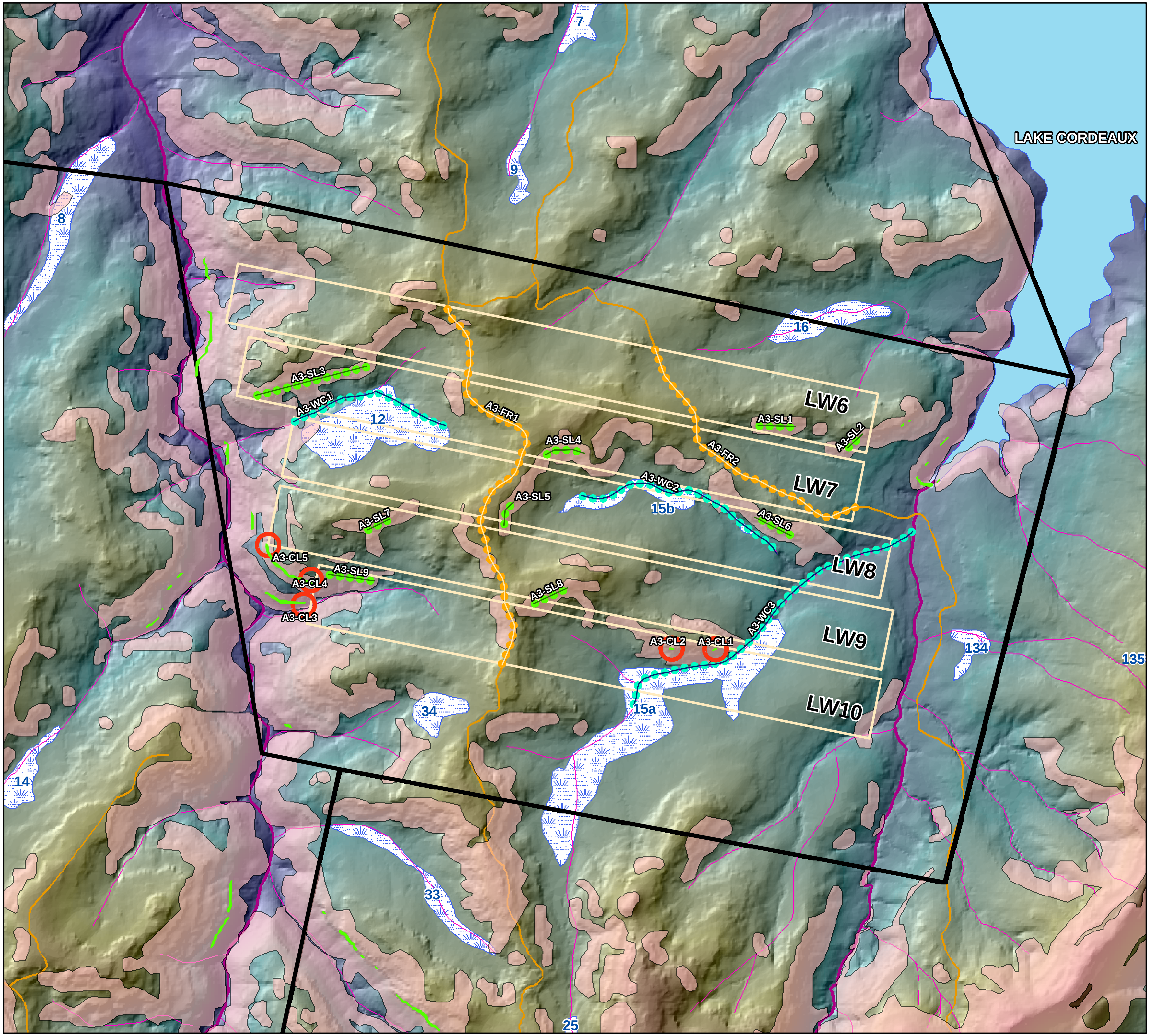
Fire Trails

A3-FR1 – The full length of the Fire Trail above Longwall Panels 6,7,8,9, and 10 and will be monitored (from MGA *X 292118.384 Y 6192037.981* to *X 291894.920 Y 6193513.172*).

A3-FR2 – The full length of the Fire Trail above Longwall Panels 6 and 7 will be monitored (form MGA *X 293584.137 Y 6192692.629* to *X 292750.889 Y 6193346.922*).

5.3. GROUND TRUTHING OF PROPOSED SITES

All proposed sites will be subject to inspections to confirm suitable access and to establish comparative photo points to commence baseline monitoring.



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Proposed Monitoring Sites

DENDROBIUM AREA 3A

Legend

- Monitoring Site (Cliffs)
- Cliffs (BIC)
- Monitoring Site (Watercourses)
- Monitoring Site (Steep Slopes)
- Monitoring Site (Fire Roads)
- Mine Layout - SMP Area 3A
- Steep Slopes
- Proposed Area 3 Footprint
- Fire Roads
- Lakes
- Rivers
- Creeks
- Minor Streams
- Swamps

Elevation:

- 500 - 550m
- 450 - 500m
- 425 - 450m
- 400 - 425m
- 350 - 400m
- 275 - 300m

N
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FIGURE 5.1

Scale 1:15,000 (at A3)

Metres
0 100 200 400 600 800 1,000

Cardno Forbes Rigby

Map Produced by Forbes Rigby Pty Ltd
Date:24 September 2007
Coordinate System: Zone 56 MGA/GDA 94
GIS MAP REF:
107055_02_2818_monitoring_sites.mxd

6. CONCLUSIONS

Based on the subsidence predictions (MSEC 2007), the location of landscape features and the experiences of Dendrobium Area 1 and 2, the locations of cliffs, slopes and fire roads at greatest risk of subsidence impacts such as rock falls, tensile cracking and subsequent erosion within Area 3 are assessed as:

- Cliffs DA3-CF7 and DA3-CF8 in Area 3A.
- Cliffs DA3-CF17 and DA3-CF18, immediately adjacent Longwall 10 in Area 3A.
- Cliffs and Rock outcrops occurring on steep slopes located within *future Goaf areas in Areas 3B & 3C*.
- The Steep slopes above 30 degrees within Goaf areas with risk increasing with slope gradient.
- Fire roads over goaf areas

For all of these features, those located at the side of the subsidence trough in positions of maximum compressive and tensile strain would generally suffer the greatest impact. Notwithstanding, the magnitude of these impacts is considered to be minor.

Numerous risk factors were considered and analysed with respect to ***swamps*** and minor ***watercourses****.* The characteristics of each swamp in Area 3 has been reviewed and documented from several previous reports and inspections.

In summary, the analysis of mining induced subsidence on swamps and minor watercourses determined:

- Swamps in Area 3 are currently in excellent condition and have been shown to be very stable over at least the last four decades.
- Analysis of predicted post-mining contours in Area 3A showed no detectable difference in the catchment sizes as a result of the mine subsidence.
- If any catchment area changes are identified in the future they are likely to be minor in nature, and are not likely to represent a major impact to the swamps, given many of the headwater swamps are known to be fed by shallow hillslope aquifers, and local minor changes in tilt are not expected to affect the drainage direction of these aquifers.
- In the absence of defined mine layout for areas 3B and 3C, we have assumed that the majority of swamps and minor watercourses in Area 3 *will lie across* longwalls (as for area 3A), and we conclude that these swamps and watercourses will be likely to undergo the landscape impact of minor gradient changes as a result of mine subsidence.
- Although there is a *higher potential* to scour where minor gradient increases occur, these changes are unlikely to result in increased scour events due to minimal increases on actual shear strengths over different flow events, the occurrence of bedrock as a control in some cases, and the lack of defined concentrated flow paths in other cases.
- Any mining induced gradient change will be less then the average grade of the swamp/watercourse and is insignificant in comparison to the natural grade variations observed in these swamps.

- Hydrological studies have found that generally, slope does not have any significant effect on sub-catchment velocities.
- Where minor gradient decreases occur, water has the potential to pool in the swamp/watercourse and no incision is likely to occur. The nature of pooling is relatively minor is not expected to result in any significant impacts other than perhaps a redistribution of vegetation in the immediate area due to increased moisture.
- By referring to swamp locations the stream order and catchment areas, Swamps 2, 5, 7, 8 and 15a appear to be the swamps at *most potential risk* of undergoing scour due to their downstream location on the drainage channel, large respective catchment areas, and therefore magnitude of flows that may be expected in large rain events.
- Monitoring by IC and EarthTech indicates the only swamps with any notable existing points of disturbance (nick points) where scour may currently be expected to be initiated are a couple of small sections of slightly scoured (but stable) channel in swamp 5 and a section of channel within swamp 8 that has been recently incised and scoured.
- In Area 3A, swamp 15a is considered the swamp at most risk of any potential mine induced subsidence impacts. This is due to it's large catchment area, considerable length, orientation over the subsidence perimeter and longwalls 9 & 10, in addition to it's relatively flat grades over significant sections.

Given that the landscape related impacts described above are assessed as being relatively minor, the primary question that remains is whether subsidence induced cracking of bedrock below and around swamps is likely to lead to significant hydrologic, water quality, or ecological impacts.

Based on the available data we have reviewed, we conclude that there is currently little evidence to indicate the proposed mining will have a significant impact on the subject swamps.

We note there is a paucity in long term swamp water balance data from undermined swamps, and rigorous pre and post mining ecological surveys. We therefore recommend detailed monitoring commence in order to increase knowledge on the issue and acknowledge there are multiple shallow borehole monitoring points recently installed in Area 2 and 3. Detailed monitoring is outlined in the area 3A Subsidence Management Plan (SMP) being submitted to the DPI for approval.

Proposed landscape monitoring locations have been identified based on areas of greatest potential risk.

Based on the MSEC subsidence predictions, the location of landscape features and the experiences of Dendrobium Area 1 and 2, we do not expect significant landscape related impacts on cliffs, slopes, fire roads, swamps and minor watercourses within Dendrobium Area 3.

Landscape impacts in Areas 3B and 3C will be assessed in detail as part of the SMP assessment and approval process for each area, when the exact mine layout will be known.

Prepared by
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